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FINAL PROGRESS REPORT

MODIFICATION OF RADIOMETER TYPE THERMISTOR DETECTORS

CONTRACT NO. NAS5 - 3320

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FINAL PROGRESS REPORT
NASA CONTRACT NAS5 - 3320

ABSTRACT

28925

This report describes the development of techniques for the application of a global silicon carbide black material to un-immersed TIROS radiometer type infrared detectors. The amount (mass/unit area) of this material required to optimize detector performance has been determined. Performance tests taken on detectors blackened with this material are compared with tests taken on similar detectors which utilize the standard Zapon black material. In all cases the global silicon carbide black material is shown to be superior to the Zapon. The effects on these detectors' characteristics due to vibration and exposure to ultraviolet radiation are also discussed.

Author

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I. INTRODUCTION

The original contract specifications defined the following goals:

1. Coating Requirements

At least 25 standard unimmersed TIROS radiometer type thermistor detectors shall be coated with a global silicon carbide black paint (hereafter GSC). A good application technique shall be developed, and the GSC shall be applied in various thicknesses. The GSC coatings shall be such that direct comparisons between performance tests of detectors coated with GSC black and detectors coated with the conventional Zapon black can be made and evaluated.

2. Performance Testing

The detector properties listed below shall be accurately measured and documented before and after each blackening experiment to evaluate the effects of the black coatings:

a. Absolute blackbody responsivity taken with a 500°K blackbody source, 15 CPS square wave chop, and electrical bandpass of 5 to 100 CPS.

b. Time constant.

c. Noise - The noise ratio (the bolometer noise with bias voltage applied to that without bias voltage applied) shall be measured in the electrical bandwidth from 5 to 100 CPS.

d. Spectral Response - The spectral response relative to a Golay cell and/or gold blackened thermocouples from 0.25 to 35 microns shall be measured before and after each blackening experiment.

3. Environmental Testing

(1) Vibration Tests

The detectors shall survive and operate when subjected to the following conditions:

a. 5-2000 CPS sinusoidal vibration with 10g rms acceleration at a sweep rate of 2 octaves/minute. Amplitude not to exceed 1/4 inch peak to peak.

b. 20-2000 CPS white noise ±3db, 10g rms in each of three orthogonal planes. The reference plane shall coincide with the plane of the detector flake. The detector shall be operated under bias during this test, and the above performance tests shall be made after vibration.

(2) Vacuum Ultraviolet (UV) Exposure

a. Exposure tests shall be performed on samples of GSC and Zapon black to determine the effects of UV radiation over prolonged periods.

b. In addition, a supplement to the original contract specified that vacuum furnace heating and atmospheric furnace heating, without the presence of UV radiation, would be performed in order to separate UV effects from effects due to "overheating" alone.

4. Chopper Mirrors

Another experiment additional to the original contract concerned the comparison of the blackened segments of TIROS chopper mirrors coated with GSC black to those coated with the standard "Murphy's" black.

II. DETERMINATION OF OPTIMUM BLACK THICKNESS

A. Application Techniques

The use of an artist's air brush for application of the global silicon carbide black was chosen at the outset because this technique allows greater control in applying the GSC black than does hand brushing. Various proportions of the solvent (Xylene) to GSC material were tried, and a ratio of two parts Xylene to one part GSC (by weight) was found to produce the most uniform coatings of the GSC black when used with 15 lbs/square inch pressure of dry nitrogen applied to the air brush. Similarly, a ratio of two parts amyl acetate to one part "Zapon" black yielded the best results for that material.

B. Preliminary Tests

Initial tests on TIROS type bolometers utilized two basic types: Nine bolometers were constructed with one-half mil Mylar backing (which is the thermal barrier between the detector flake and the sapphire heat sink) and six with one-quarter mil backing. When blackened with equal amounts of GSC black, the one-quarter mil Mylar detectors produced the best overall results for purposes of evaluation. Specifically, the spectral response of the faster (quarter-mil) detectors was more uniform than that of the half-mil detectors. Moreover, the time constants of the faster detectors (blackened and unblackened) were in a range such as to allow more accurate measurements using the frequency response techniques. The remaining detectors used in this evaluation program utilized one-quarter mil Mylar backing.

C. Optimum Mass Determination for GSC and Zapon Blacks

In order to determine how the signal or responsivity of a detector can be optimized within the tolerance of a specified time constant, the characteristics of two detector units (numbers 3992, and 3994) were measured on the Bolometer Response Analyzer (BRA) prior to the blackening. Thereafter, each bolometer was blackened with successive increments of black material, and BRA measurements taken after each application. (Detector #3994 was blackened with GSC and #3992 with Zapon). The results of this series of tests are shown in Tables I and II. These tables essentially give the responsivity and time constant as a function of mass/unit area for each black material. Figure I is a plot of this data, from which the marked superiority of the GSC black over the Zapon can easily be seen. Quantitatively the data reveals that the ratio of maximum responsivity to minimum (unblackened) responsivity is 1.62 for the GSC material, and only 1.38 for Zapon. Moreover, this optimizing of responsivity is accompanied by a 1.0 ms increase in time constant for the GSC, while the Zapon causes an increase of 1.3 ms at maximum responsivity. The optimum mass/area was determined to be about 2.4 ±0.2 mg/cm^2 for both GSC and Zapon. One concludes from this data that the blackening of a detector can be tailored to meet specific time constant and responsivity requirements. Thus, by fabricating an unblackened TIROS type detector with a time constant about 1.0 ms to 1.5 ms less than the maximum specified time constant, optimum responsivity can be achieved without exceeding the specified time constant for the finished device.

D. Comparison of Chopper Mirrors

Acting on a combined suggestion from NASA and BEC, the blackened segments of the TIROS radiometer chopper mirrors were coated with GSC black material for comparison with the mirrors presently blackened with "Murphy's" black, which has been the conventional IR absorber used on chopper mirrors of the five-channel radiometer to date.

Total reflection of the blackened surface at 5 degrees incidence was measured on a Beckman DK-2 spectrophotometer from 0.25 microns to 2.5 microns. Specular reflectance measurements at 30 degrees incidence were made at the longer wavelengths (2 microns to 35 microns) on the Beckman IR-5 and IR-5A recording spectrophotometers.

The GSC material exhibited much lower total reflection at the shorter wavelengths (0.25 microns to 2.5 microns) than did the "Murphy's" flat black. The specular reflectance measurements, however, showed no significant difference between the two materials in the range from 2 microns to 16 microns.

It is well to point out that specular reflectance and/or transmission measurements at the longer wavelengths beyond 2.5 microns are, by their nature, incapable of showing up differences between instruments at these extremely low reflectivities. Therefore, the basic tool used for comparison of the two IR absorbers was relative spectral response measurement, rather than any absolute measurement.

The chopper mirrors were subjected to the equivalent of 75 hours of solar ultraviolet radiation in vacuo. Both total and specular reflectance measurements made after UV irradiation show no significant change in either of the blackening materials. Figure II is a representative plot of the total reflectance measurements in the range from 0.25 microns to 2.5 microns.

III. ENVIRONMENTAL TESTS

A. Twelve detector assemblies were submitted for vibration testing after their electrical properties had been measured. Figure 3 indicates the type, intensity, and duration of the vibration tests. Table III shows the electrical parameters of the detectors before and after testing. The results showed no significant changes in the detector parameters due to vibration testing. (Note that four of the twelve detectors were destroyed as a result of human error.)

B. Solar Ultraviolet Radiation and High Temperature Backing

The first efforts to determine the effects of vacuum ultraviolet radiation upon the GSC and Zapon materials were strictly qualitative. Various thicknesses of the two materials were applied to commercial quartz substrates, which were then subjected under vacuum (20 to 27 microns Hg) to the equivalent of 76 hours of solar UV radiation. Visual inspection after radiation revealed a distinct yellowing and surface change in the Zapon material, whereas the GSC samples showed no discernible change. It was intended to follow this test with exposure of TIROS detectors to the same radiation, but it was noted that the assemblies would have to be rebuilt without Mylar backing in view of the high substrate temperatures achieved during the test (Approx. 180°C). This further suggested that any changes in the black materials due to UV tests might be caused by elevated temperatures alone, thus it became necessary to design experiments to separate the UV effects from the purely thermal effects.

Consequently, blackened quartz samples similar to the above were subjected to extensive "bake-outs" at 180 to 200°C both in vacuum and in atmosphere, with no ultraviolet present. The mass of black material was measured before and after bake-out. In both cases the Zapon samples showed distinct yellowing after bake-out, while the GSC samples were visually unchanged. As to change of mass, the Zapon lost from 60 to 75% of its mass after baking, while the GSC lost only 13% nominally. Most probably these losses are due to evaporation of the binder materials in the blacks. On the basis of the relatively large mass loss observed with the Zapon material, Zapon black has been tentatively removed as a blackening agent on future five-channel radiometers, since the large mass change causes proportionally large changes in the time constant of a given device, and a consequent invalidation of any previous radiometric calibration of the detector.

Reflectance measurements were also taken before and after baking, and these are shown in Figure 4. As might be expected, the reflectance at the shorter wavelengths (from 0.25 microns to 2.5 microns) of the Zapon is appreciably increased by baking, while that of the GSC is unchanged (Specular Reflectance measurements at longer wavelengths from 2 to 35 microns shows no changes, and thus are not shown for the reasons previously discussed in Section I-D of this report.)

C. Ultraviolet and High Temperature Effects on Detector Parameters

Tests of these effects on detectors utilized four detector assemblies, two of which were blackened with Zapon and two with GSC. These were subjected to the equivalent of 75 hours of solar UV radiation in Vacuo, and their relating spectral response was measured before and after exposure. The most marked change in response of the Zapon blackened detectors (Figures 5 and 6) is the decrease in overall response as a function of wavelength after UV exposure. Surprisingly, the changes in the GSC blackened detectors were more obvious (Figures 7 and 8). The overall response after exposure was significantly lower. The greater change was evident on the sample with the greater mass of GSC.

Despite the apparent larger change in relative spectral response of the GSC blackened samples, it must be pointed out that the relative signal at $\lambda = 2$ microns is significantly higher for the GSC samples over the Zapon blackened detectors (See Table IV, below.) All 4 of the test detectors were operated under the same time constant (4.2 ms to 5 ms.) Thus, the relative signals measured at a given wavelength show dramatically the gain in IR absorption of the GSC black over conventional Zapon. Figure A, below, was drawn from the data on Figures 5, 6, 7, and 8; and Table IV.

FIGURE A

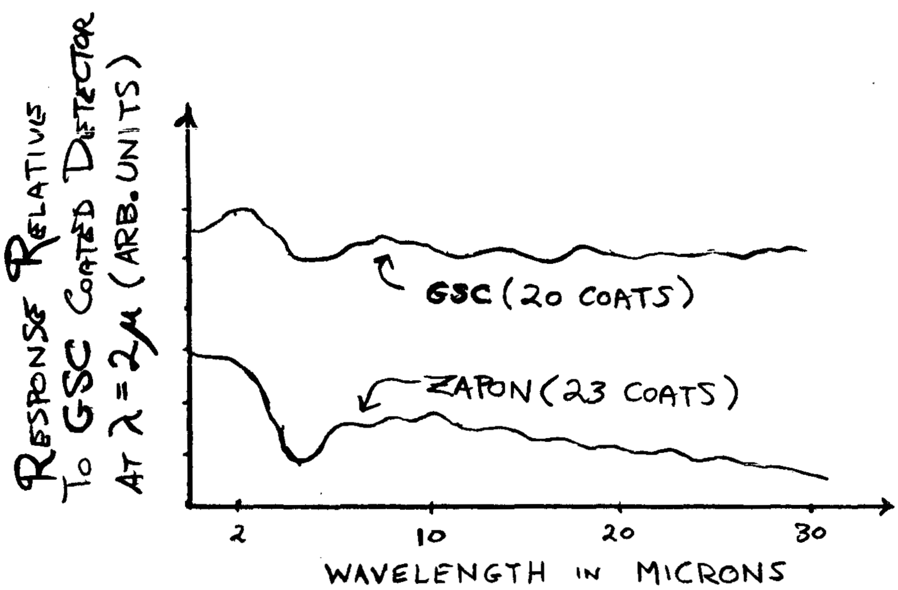


TABLE IV

	BLACK	# COATS	RELATIVE SIGNAL AT $\lambda = 2$ microns
#660- 8/29	Zapon	10 Coats	2.5 mv
#570- 8/29	Zapon	20 Coats	2.78 mv
#731- 8/29	GSC	10 Coats	4.5 mv
#698- 8/29	GSC	20 Coats	6.0 mv

Another important detail to be seen from these data plots is that by use of the GSC as an IR absorber, the sharp drop in relative response at 5 microns is eliminated (Figures 7 and 8) but remains strikingly evident when compared to Figures 5 and 6, concerning the Zapon material.

To further test the hypothesis that these changes are primarily due to excessive heating, rather than UV radiation per se, four TIROS detector units (#'s3988, 3989, 3990, and 3991) were blackened two each with Zapon and GSC materials in preparation for random temperature cycling between 25°C and 135°C. The temperature cycling, shown in Figure 9, was performed at atmospheric pressures and was of one week's duration.

Table V is the compilation of detector data taken before and after the cycling on the Bolometer Response Analyzer. Note that the <u>only</u> significant changes occur in the time constants, with the Zapon detectors exhibiting the larger changes. This is to be expected due to the relatively large mass loss phenomenon previously discussed, which results in a large change of "thermal mass" and a consequently large change in time constant.

IV. FINAL EVALUATION TESTS

To obtain a comprehensive comparison between the 2 materials (GSC and Zapon) the IR detection properties (time constant, signal, noise, etc.) of eight devices were measured before blackening, during and after blackening, and following baking in the atmosphere and in vacuum. The above measurements were made in response to a 470°K blackbody using a 15 CPS square wave chop (half-duty cycle). To augment the above measurements, the frequency response of the detectors was measured out to 100 CPS to show the relative response change undergone by the detectors, due to blackening and baking at the frequency (46 CPS) presently being used on the TIROS weather satellite. Figures 10 through 17 are the data plots of the frequency response measurements.

Returning to the blackening of the 8 detectors involved, the IR absorbing material (GSC and Zapon) was applied in 2 steps. The first application of the blackening agents was tailored to achieve half of the amount mass/unit area found to produce maximum signal and/or responsivity. In a monthly progress report (Oct.1963) the desired amount mass/unit area for the GSC material was found to be 2.2 mg/cm^2 to 2.6 mg/cm^2 and 2.1 mg/cm^2 to 2.6 mg/cm^2 for the Zapon (See Figure I, and Tables I and II.)

Following the measurements on the detectors the second application of black was then applied to the active flake to increase the blackening mass to approximately the aforementioned amounts.

Table VI is the data compilation of the detector measurements made on the Bolometer Response Analyzer using a 470°K blackbody producing an irradiance of 14.5 microns w/mm^2, chopped at 15 CPS (half-duty cycle - square wave) incident on the detector.

Concerning the bake-out to which the detectors were subjected, 4 of the units (#'s 3980, 3981, 3982, and 3985) were baked at 180°C to 200°C in the atmosphere for 15 hours. The second group of 4 detectors (#'s 3974, 3975, 3977, and 3983) were subjected to the same temperature for the same length of time but in a vacuum equal to or less than 5×10^{-5} mm Hg. Two of the above detectors (#'s 3981 and 3982) following the measurements made after the bake-out tests, were subjected to the environmental requirements (vibration) as outlined in paragraph II-3 (1)- A & B of the work statement pertaining to NASA Contract NAS5 - 3320. Figure 3 is the plot of the sine wave and random (white noise) vibration that the 2 detectors (#'s 3973 and 3978) underwent after blackening. The response analyzer measurements on these 2 detectors are also included in the data compilation in Table VI.

Normalizing the data in Table VI as a function of time constant and bias voltage, brings out the fact that the GSC consistently results in an IR detector which, time constant and bias being equal, has increased signal and/or responsivity over a detector blackened with Zapon. Furthermore, past experiments have definitely shown that in a simulated hostile environment such as encountered in space satellite work, that the GSC material undergoes far less mass change in comparison to Zapon as discussed on page 5.

SYMBOLS USED IN THE FOLLOWING TABLES

N_O = Detector noise without bias applied (plus system noise) in microvolts (μv).

N_B = Detector noise with bias applied in μv.

N_B/N_O = Noise Ratio

I_B = Detector Bias Current

Sig. = Detector Signal in μv.

Sig. Roof = Signal with Radiation On Open Flake in μv.

Sig. AO = Signal with Aperture Open.

Resp. = Responsivity in volts per watt incident on the detector (V/W).

τ = Time Constant in milliseconds (ms).

TABLE I

OPERATING CHARACTERISTICS VS. PROGRESSIVE BLACKENING

Material: GSC

Detector: 3994 - Solid Backed TIROS

V_{Bias}: ±112.5 volts

Trial #	Total # of Coats	Total mass (mg)	mg/cm^2	N_O (μv)	N_B (μv)	N_B/N_O	I_B (μa)	Sig. Roof/AO (μv)	Resp. V/W	τ (ms)
0	0	0	0	.875	1.15	1.3	490	67.5/458	119	2.4
1	5	.0012	.68	.875	.88	1	540	87/568	152	2.5
2	10	.0017	.96	.89	.96	1.08	520	94.6/650	165	2.5
3	15	.0025	1.4	.76	.95	1.25	520	99.8/680	175	2.8
4	20	.0033	1.9	.8	.85	1.06	540	109/720	191	3.1
5	25	.0039	2.2	.7	.73	1.04	560	111/720	193	3.4
6	30	.0045	2.6	.95	1.1	1.16	560	109/720	191	3.7
7	35	.0050	2.9	.87	.95	1.1	560	108/718	189	4.2
8	40	.0058	3.3	.84	.93	1.11	560	107/716	187	4.6
9	45	.0066	3.8	.70	.90	1.27	570	106/700	186	5.4
10	50	.0073	4.2	.85	1.2	1.18	510	102/684	178	5.9

TABLE II

OPERATING CHARACTERISTICS VS. PROGRESSIVE BLACKENING

Material: Zapon

Detector: 3992 - Solid Backed TIROS

V_{BIAS}: ±112.5 volts

Trial #	Total # of Coats	Total mass (mg)	mg/cm^2	N_0 (μv)	N_B (μv)	N_B/N_0	I_B (μa)	Sig. Roof/AO (μv)	Resp. V/W	τ (ms)
0	--	-----	---	0.68	0.79	1.15	520	66/460	115	2.3
1	5	.0008	0.45	0.75	0.95	1.27	530	74/520	130	2.7
2	10	.0014	0.8	0.77	0.83	1.07	530	80/550	140	2.6
3	15	.0017	0.97	0.77	0.85	1.1	540	83/582	145	2.6
4	20	.0024	1.36	0.76	0.84	1.1	540	88.4/610	155	3.0
5	25	.0030	1.7	0.78	0.86	1.1	560	88/616	154	3.5
6	30	.0037	2.1	0.74	0.79	1.07	560	91/628	159	3.6
7	35	.0042	2.38	0.74	0.74	1.0	550	91/630	159	4.1
8	40	.0046	2.6	0.70	0.74	1.05	580	91/630	159	4.4
9	45	.0052	2.96	0.70	0.77	1.1	570	91/630	159	4.7
10	50	.0058	3.3	0.70	0.77	1.1	590	91/630	159	5.4

TABLE III

Detector Parameters Before and After Vibration Testing

Detector #	V_B	N_O	N_B/N_O	Sig.	T.C.
3971	90	.560	1.16	133	5.9
3972	90	.550	1.18	130	5.9
3977	90	.560	1.17	116	4.8
3978	90	.550	1.12	118	5.2
3980	112.5	.560	1.96	99	4.1
3981	112.5	.550	1.17	90	2.7
3982	112.5	.550	1.17	94	2.9
3989*	112.5	.560	(A 1.96)* 1.5(C 1.14)	119	4.9

$$\left.\begin{array}{l}3973\\3974\\3975\\3976\end{array}\right\}$$ Blown due to human error during bias application.

* The only measurable change after vibrational testing was the increased noise in the Active flake in this detector. The compensator C remained unchanged.

TABLE V

Det. #	*1	Black and Coating Mass	Noise w/o bias N_O (μv)	Noise w bias N_b (μv)	V_{BIAS} (volts)	I_{BIAS} (μa)	Signal ROOF/AO	τ (ms)	Resp. V/W
3998	B	GSC	0.65	1.0	±112.5	500	97/670	2.8	170
	A	.85 mg/cm^2	0.74	1.64	±112.5	530	97.4/674	2.4	170
3989	B	GSC	0.65	0.75	±112.5	600	108/700	3.1	189
	A	1.36 mg/cm^2	0.75	0.87	±112.5	600	104/700	2.8	182
3990	B	Zapon	0.67	0.83	±112.5	530	84/582	2.8	147
	A	0.74 mg/cm^2	0.7	0.93	±112.5	590	80/552	2.2	140
3991	B	Zapon	0.71	0.8	±112.5	530	83/644	2.9	145
	A	1.2 mg/cm^2	0.75	0.97	±112.5	570	88.5/618	2.2	155

* B - Before Temperature Cycling
A - After Temperature Cycling

TABLE VI

ATMOSPHERE

Detector # and Black	UNBLACKENED No μv	Nb μv	Ib μa	Sig μv	τ ms	1st APPLICATION OF BLACK * No μv	Nb μv	Ib μa	Sig μv	τ ms
3980 GSC	.67	.89	570	378	2.2	.69	.8	540	620	3.1
3981 GSC	.8	.95	570	396	2.4	.7	.8	540	618	3.5
3982 Z	.8	.96	560	436	2.5	.65	.78	540	554	3.3
3985 Z	.74	.87	570	436	2.9	.67	.81	530	600	3.7

VACUUM

Detector # and Black	UNBLACKENED No μv	Nb μv	Ib μa	Sig μv	τ ms	POST APPLICATION OF 1st BLACK No μv	Nb μv	Ib μa	Sig μv	τ ms
3974 GSC	.72	.8	320	420	4.6	.7	.8	260	650	5.4
3975 GSC	.75	.8	300	426	5.2	.64	.75	320	650	6.5
3977 Z	.72	.8	320	372	4.7	.65	.73	290	552	5.6
3983 Z	.77	.9	580	412	2.8	.70	.77	570	541	3.2

*First Application of the Blackening Material - Mass/Unit Area
GSC: 1.9 mg/cm^2 Z: 0.98 mg/cm^2
Final Application of the Blackening Material - Mass/Unit Area
GSC: 2.9 mg/cm^2 Z: 2.2 mg/cm^2

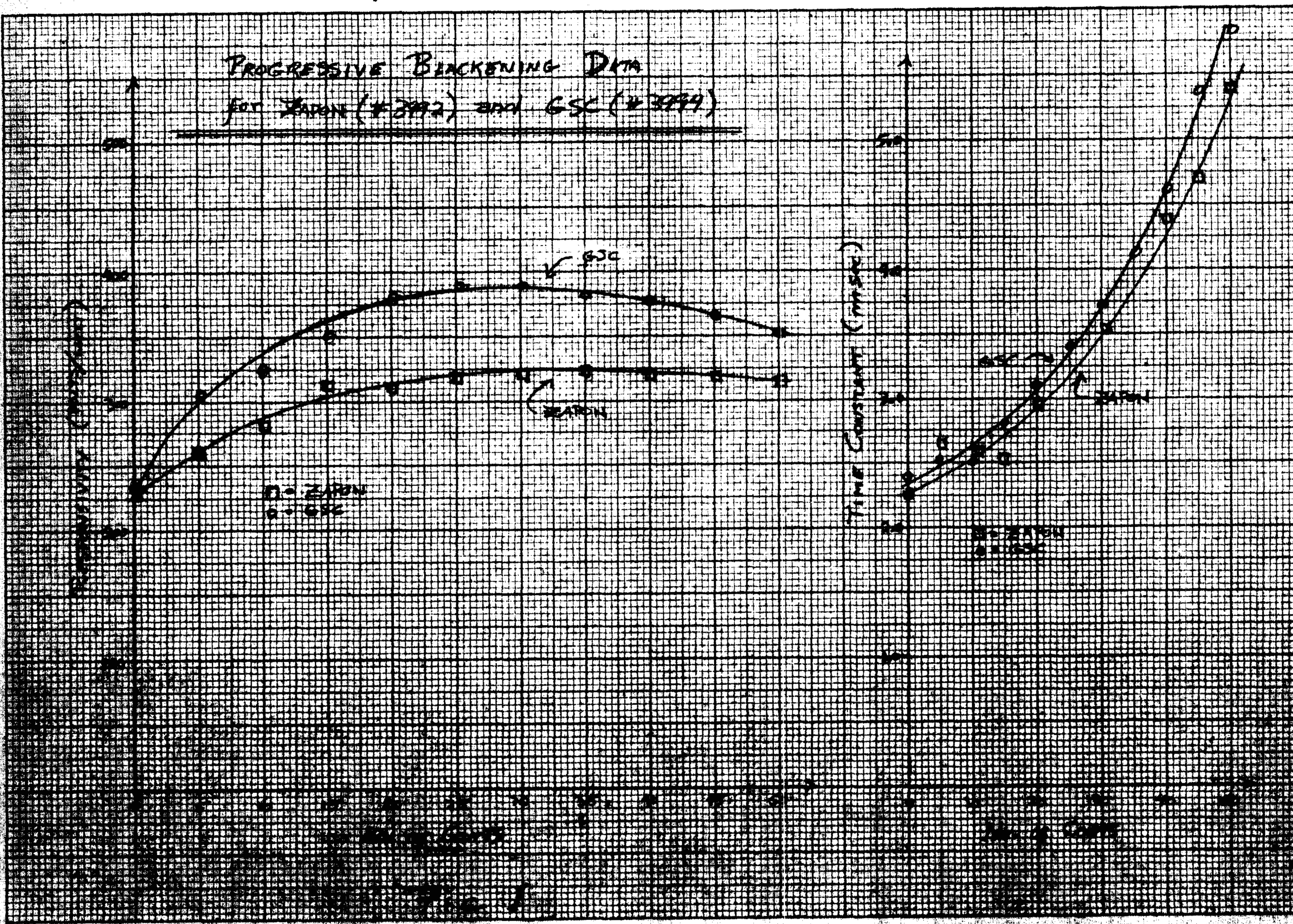
Continued on next page

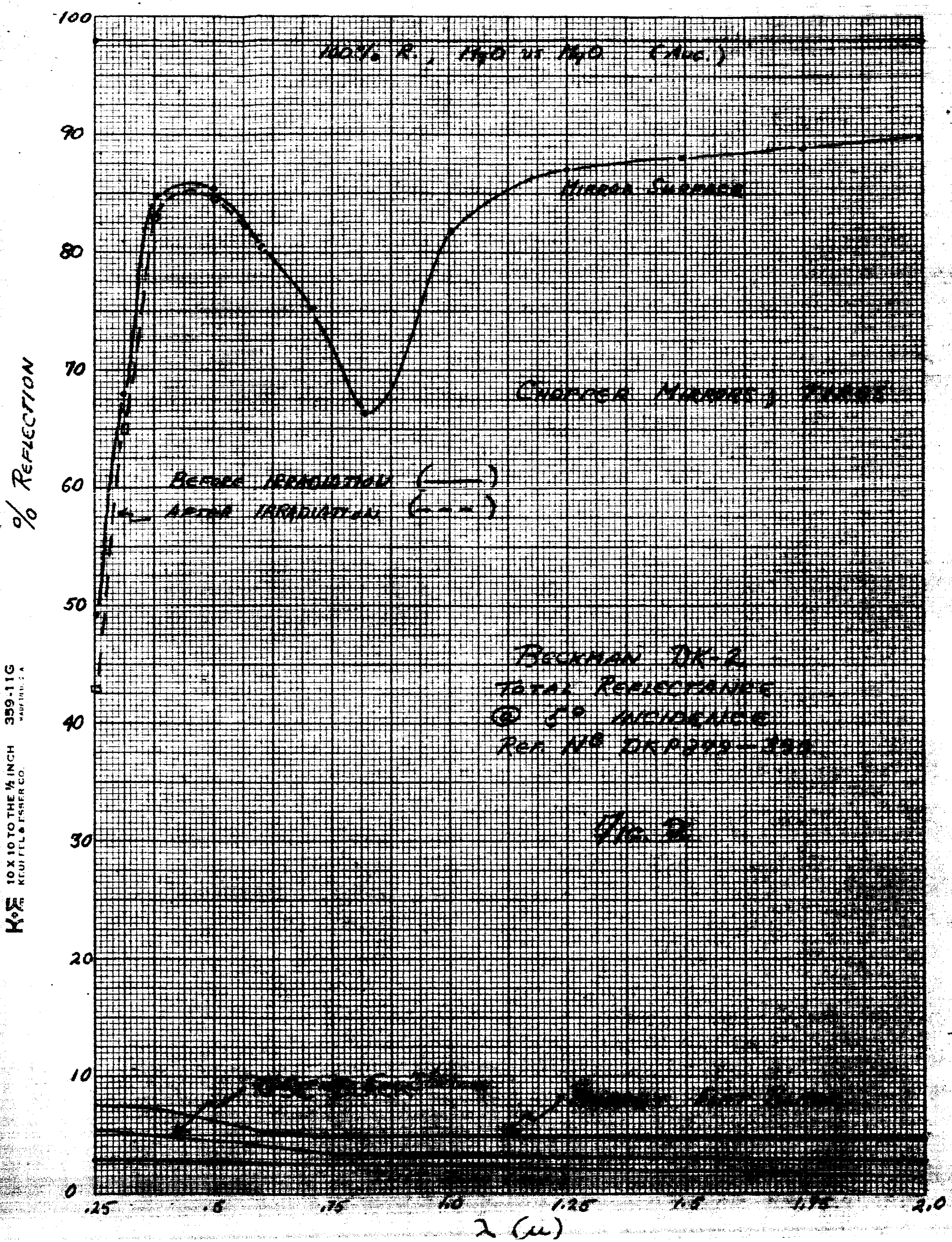
TABLE VI CONTINUED

	ATMOSPHERE					ATMOSPHERE						ENVIRONMENTAL					
	FINAL APPLICATION OF BLACK *					POST BAKEOUT						AFTER VIBRATION					
Detector # and Black	No μv	Nb μv	Ib μa	Sig μv	τ ms	No μv	Nb μv	Ib μa	Sig μv	τ ms	V Bias Volts	No μv	Nb μv	Ib μa	Sig μv	τ ms	V Bias Volts
3980 GSC	.54	.7	600	634	3.6	.7	1.36	610	623	3.5	±112.5						
3981 GSC	.55	.66	600	634	4.2	.7	2.2	620	620	3.6	±112.5	.67	2.2	610	660	4.1	±112.5
3982 Z	.55	.66	570	620	3.5	.68	.95	620	600	3.6	±112.5	.66	1.4	640	600	2.9	±112.5
3985 Z	.56	.7	570	680	4.2	.65	1.6	580	660	3.1	±112.5						

Detector # and Black	No μv	Nb μv	Ib μa	Sig μv	τ ms	No μv	Nb μv	Ib μa	Sig μv	τ ms	V Bias Volts
3974 GSC	.55	.62	340	650	6.2	.7	.8	320	650	6.2	±67.5
3975 GSC	.56	.62	300	670	6.5	.65	.76	310	682	6.5	±67.5
3977 Z	.55	.64	330	580	5.8	.66	.78	300	620	5.9	±67.5
3983 Z	.55	.67	630	590	3.5	.7	.86	640	580	3.4	±112.5

*First Application of the Blackening Material - Mass/Unit Area
GSC: 1.9 mg/cm^2 Z: 0.98 mg/cm^2
Final Application of the Blackening Material - Mass/Unit Area
GSC: 2.9 mg/cm^2 Z: 2.2 mg/cm^2


PROGRESSIVE BLACKENING DATA
FOR ZARON (#3992) AND GSC (#3994)
GSC
ZARON
□ = ZARON
○ = GSC
TIME CONSTANT (MSEC)
GSC
ZARON
□ = ZARON
○ = GSC


100% R., MgO vs MgO (Avc.)
Mirror Surface
Chopper Mirror; Three
Before Irradiation (——)
After Irradiation (- - -)
Beckman DK-2
Total Reflectance
@ 5° Incidence
Ref. No DKP
% Reflection
λ (μ)
K+E 10 X 10 TO THE ½ INCH 359-11G
KEUFFEL & ESSER CO.
100
90
80
70
60
50
40
30
20
10
0
.25
.5
.75
1.0
1.25
1.5
1.75
2.0
Fig. 2

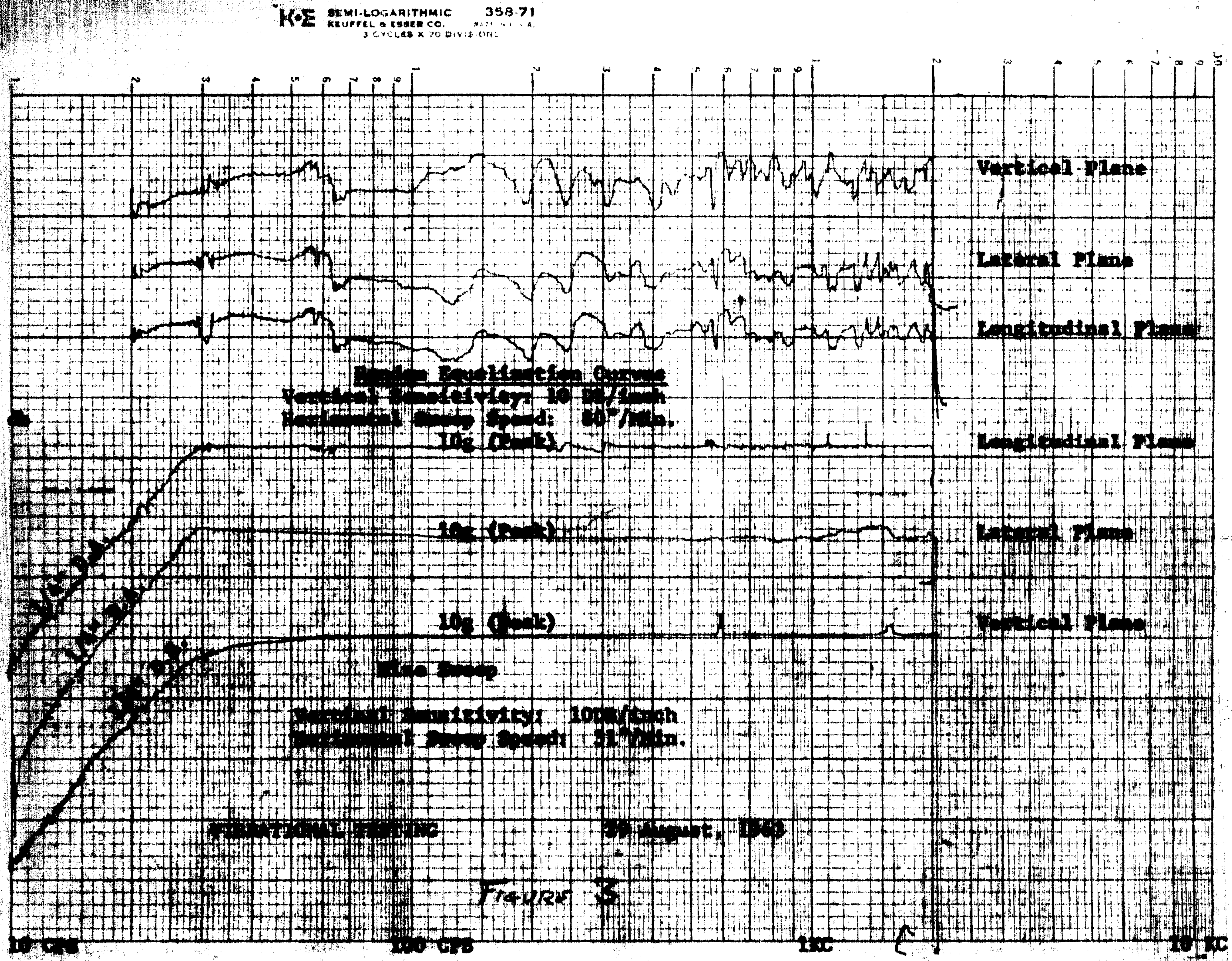

K+E SEMI-LOGARITHMIC 358-71
KEUFFEL & ESSER CO.
3 CYCLES X 70 DIVISIONS
Vertical Plane
Lateral Plane
Longitudinal Plane
Random Equalization Curves
10g (Peak)
Longitudinal Plane
10g (Peak)
Lateral Plane
10g (Peak)
Vertical Plane
Sine Sweep
August, 1963
10 CPS
100 CPS
1KC
10 KC

FIGURE 3

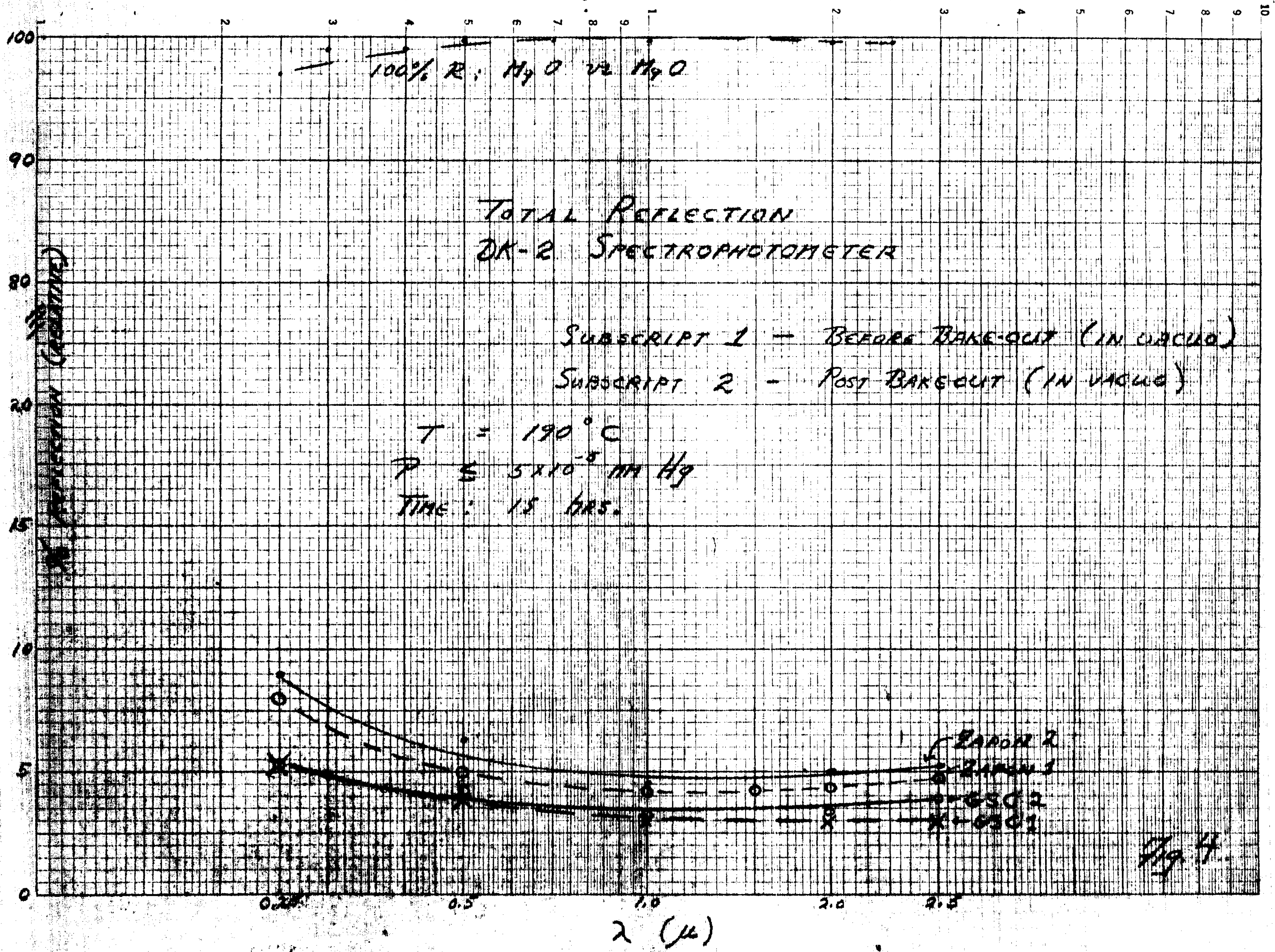
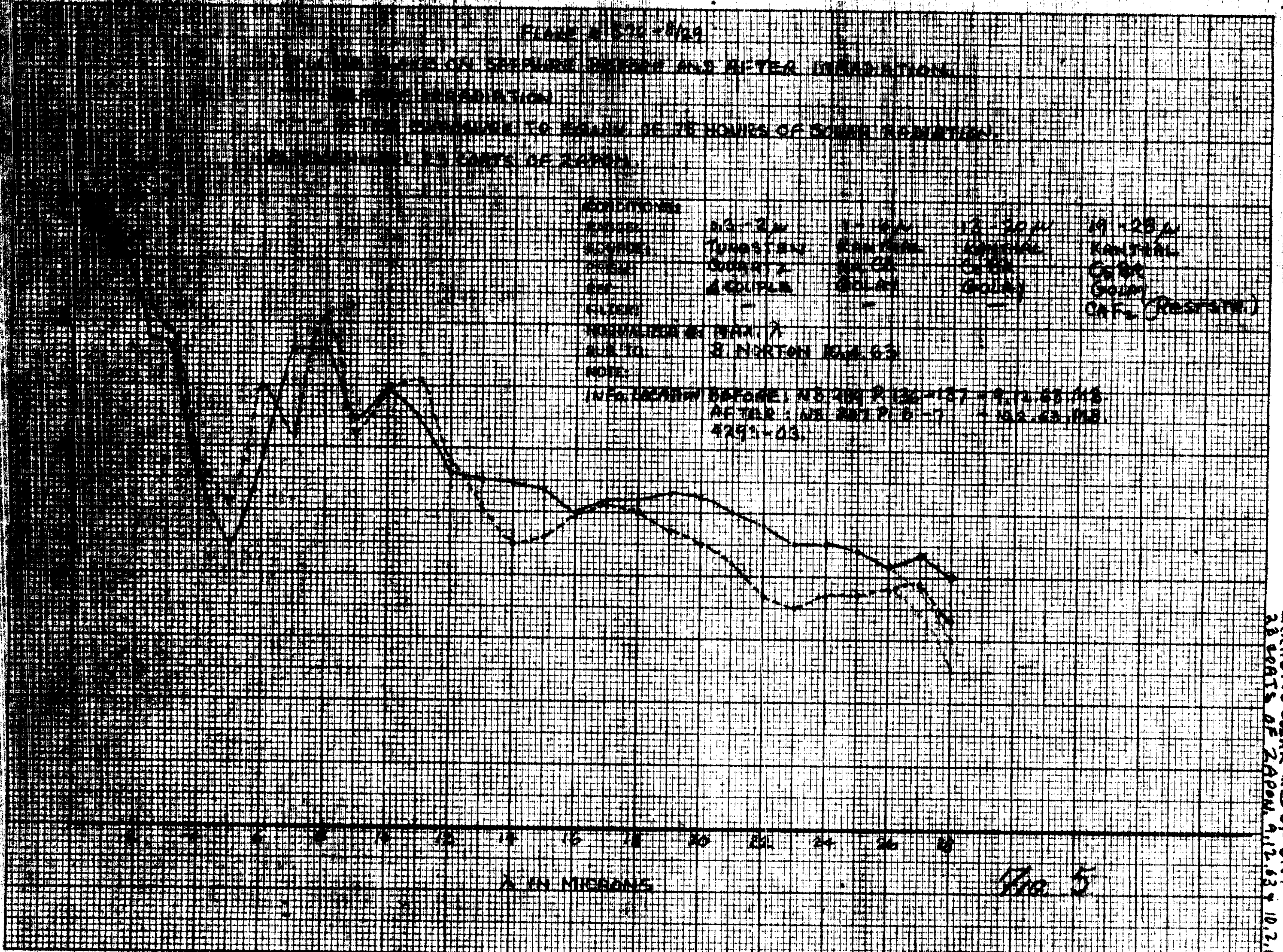
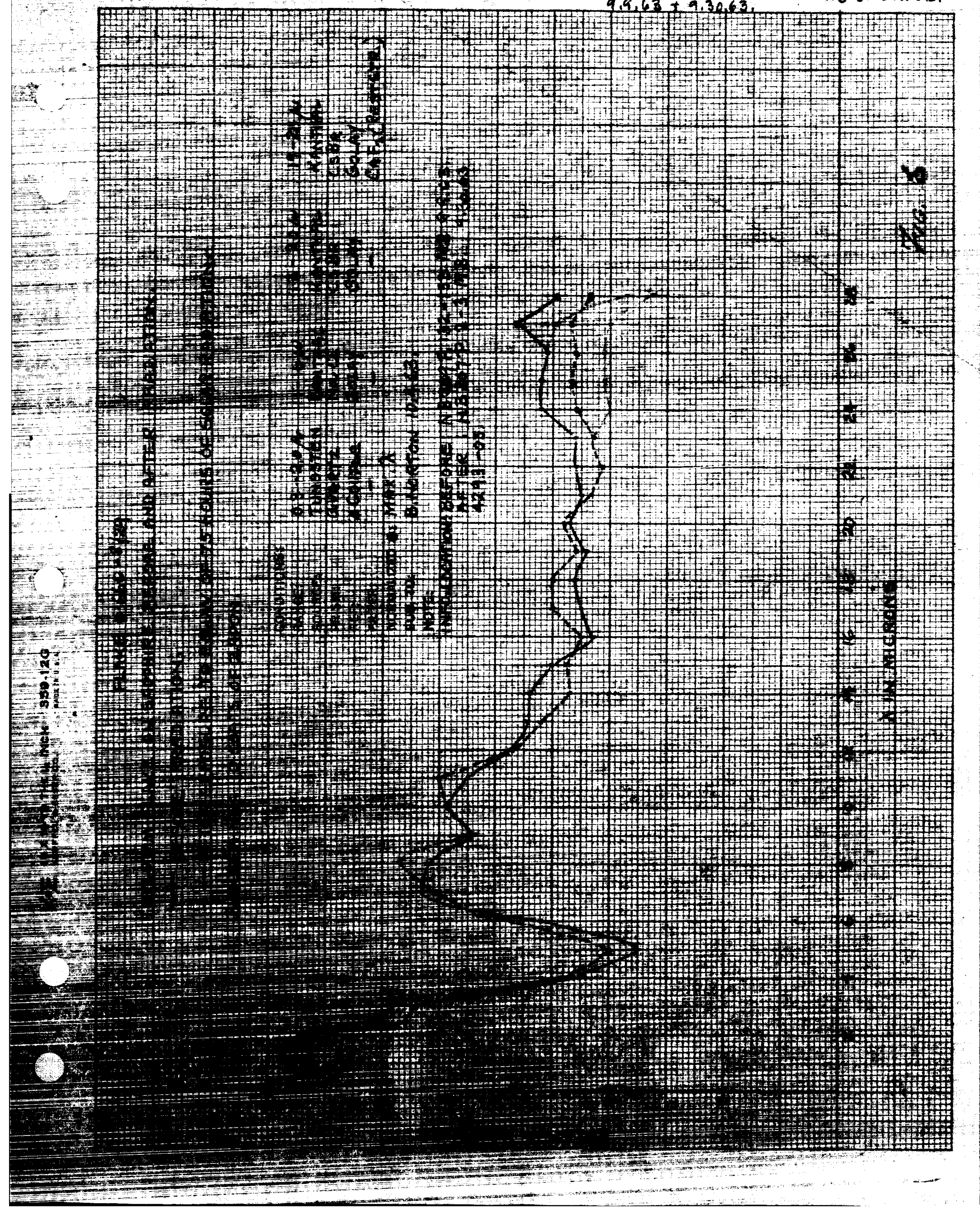

100% R: MgO vs MgO
TOTAL REFLECTION
DK-2 SPECTROPHOTOMETER
SUBSCRIPT 1 — BEFORE BAKE-OUT (IN VACUO)
SUBSCRIPT 2 — POST BAKEOUT (IN VACUO)
T = 190 °C
P ≤ 5x10^-5 mm Hg
TIME: 15 HRS.
ZAPON 2
ZAPON 1
GSC 2
GSC 1
% REFLECTION (RELATIVE)
λ (μ)

Fig. 4

FLAKE # 570-8/29 BEFORE & AFTER
IRRAD. 75 SOLAR HRS OF U.V.
28 COATS OF ZAPON, 9.12.63 & 10.2.63



FLAKE # 660-812G BEFORE + AFTER IRRADIATION
75 SOLAR HOURS OF U.V. 10 COATS OF ZAPON.
9.9.63 + 9.30.63.



FLAKE # 731-8/29 BEFORE + AFTER IRRADIATION
75 HOURS OF SOLAR U.V. 10 COATS OF GSC
9.3.63 + 10.1.63.

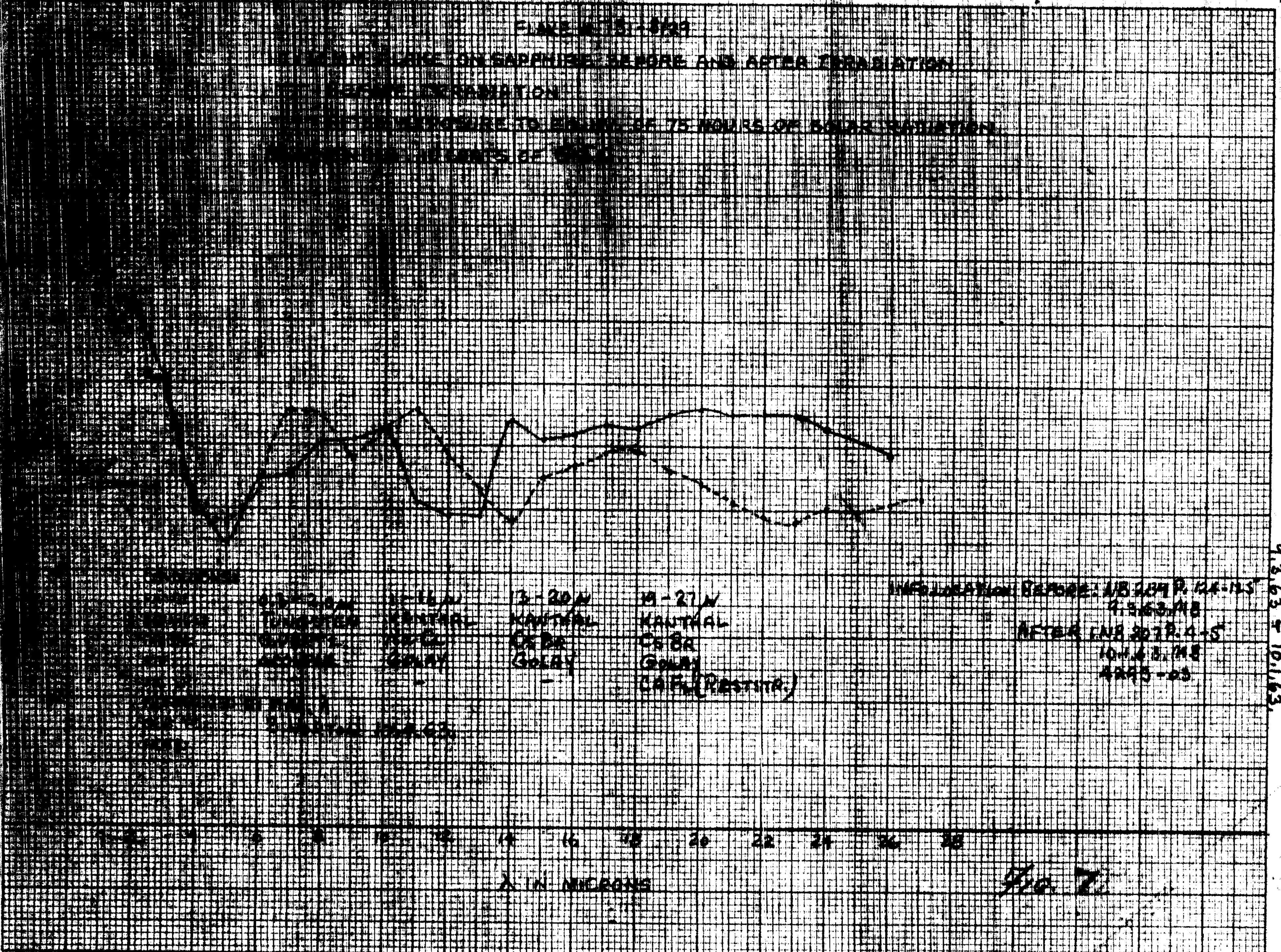
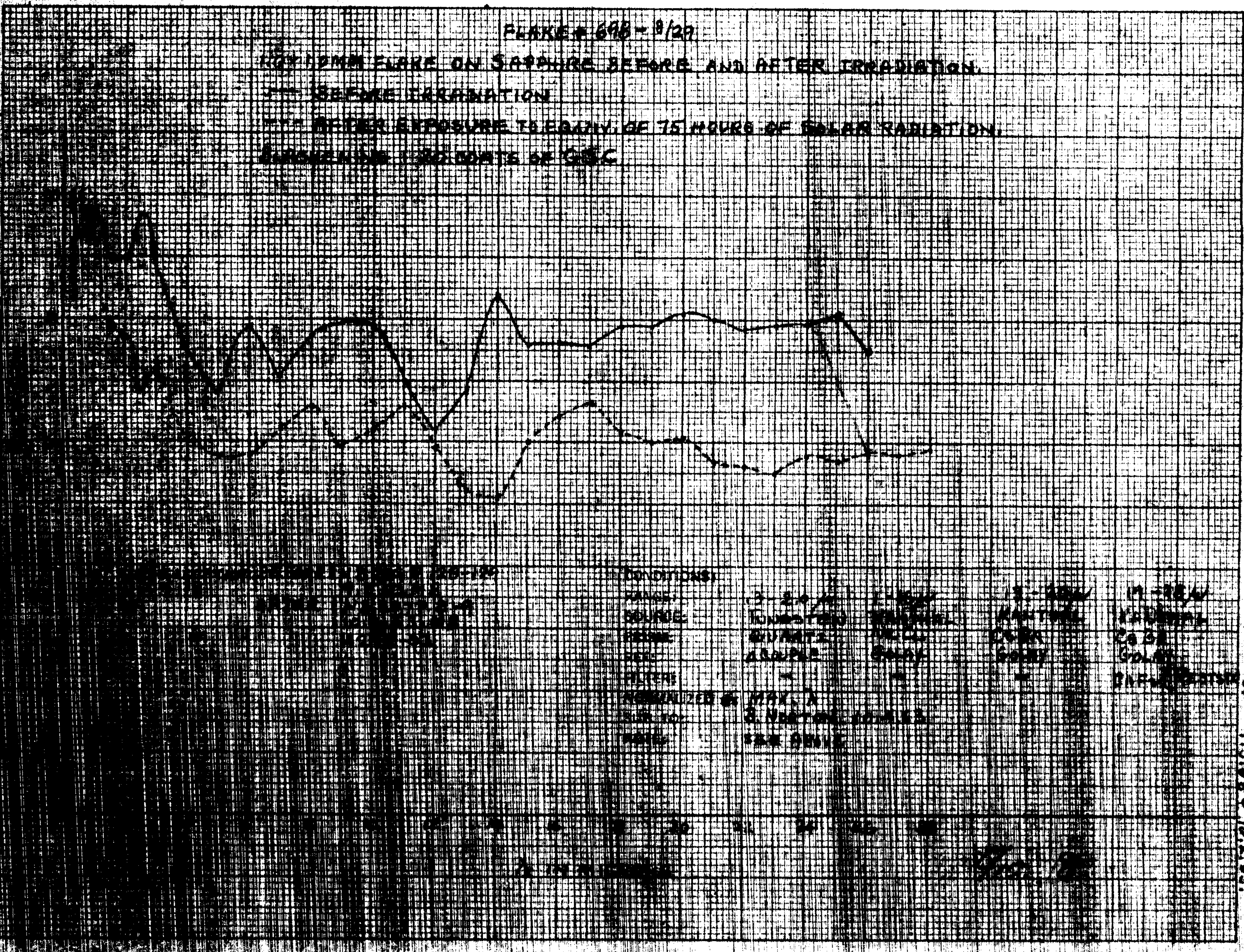


Fig. 2

FLAKE # 698-8/29 BEFORE + AFTER IRRAD.
20 COATS OF GSC
75 SOLAR HRS. OF U.V.
9.5.63 + 10.2.63.

K+E 10 X 10 TO THE ½ INCH 359-12G
KEUFFEL & ESSER CO. MADE IN U.S.A.



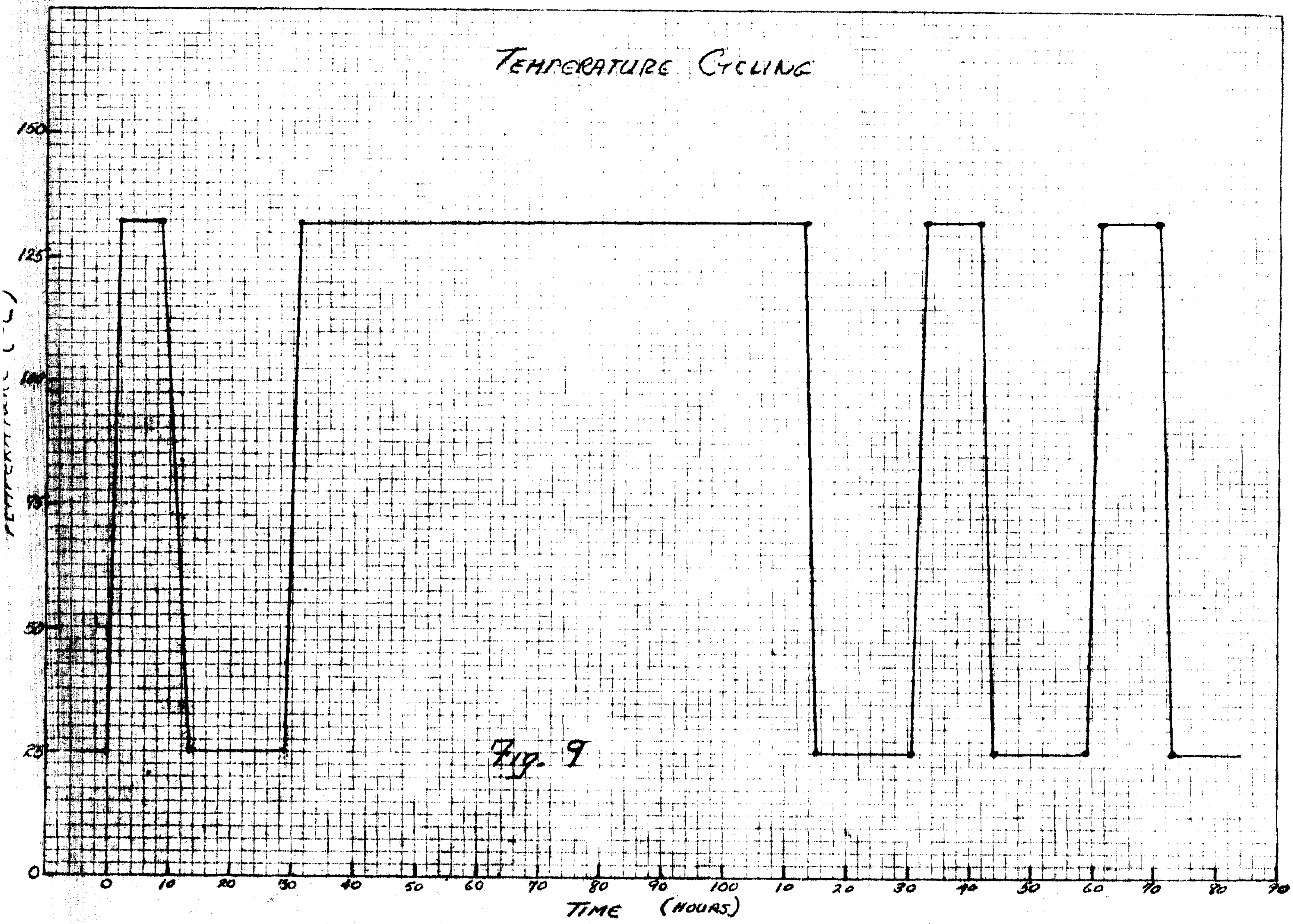
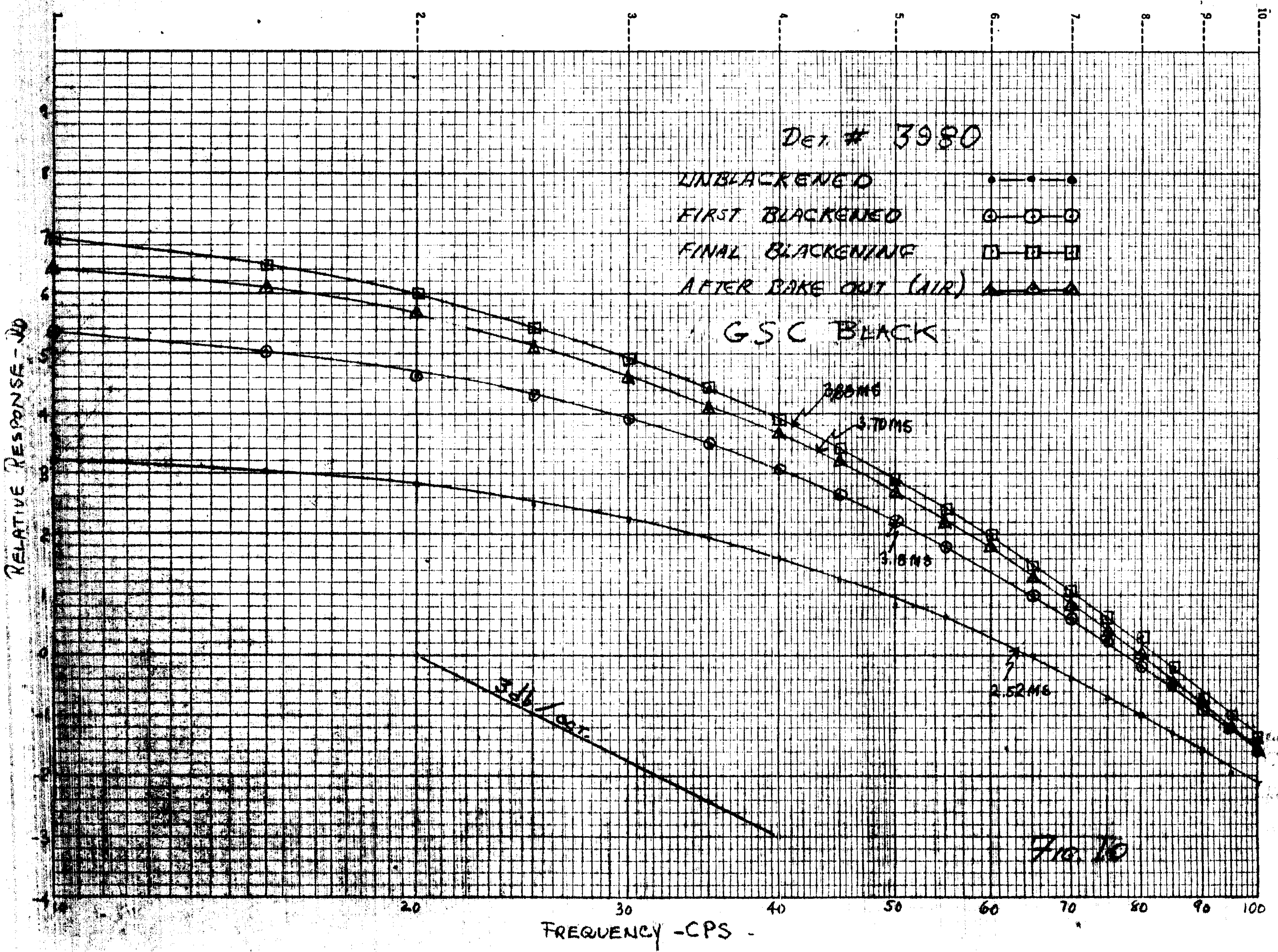

TEMPERATURE CYCLING
150
125
100
75
50
25
0
0
10
20
30
40
50
60
70
80
90
100
10
20
30
40
50
60
70
80
90
TIME (HOURS)

Fig. 9


DET. # 3980
UNBLACKENED
FIRST BLACKENED
FINAL BLACKENING
AFTER BAKE OUT (AIR)
GSC BLACK
3.70MS
3.6MS
2.52MS
3db/oct.
RELATIVE RESPONSE - db
FREQUENCY - CPS -
Fig. 10

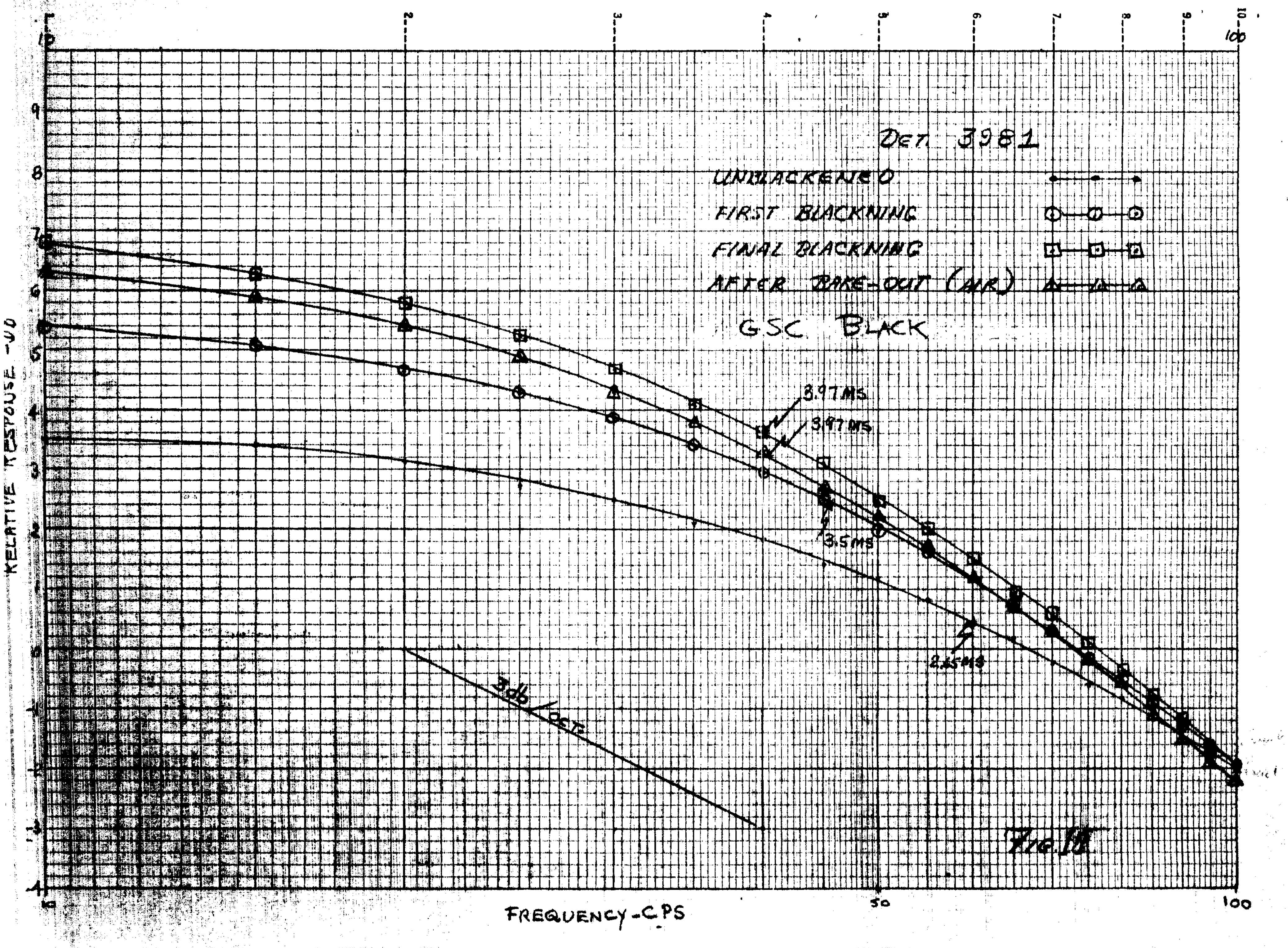

DET. 3981
UNBLACKENED
FIRST BLACKNING
FINAL BLACKNING
AFTER BAKE-OUT (AIR)
GSC BLACK
3.97 MS
3.97 MS
3.5 MS
2.45 MS
3db/OCT.
RELATIVE RESPONSE -DB
FREQUENCY-CPS
10
50
100

FIG. 18

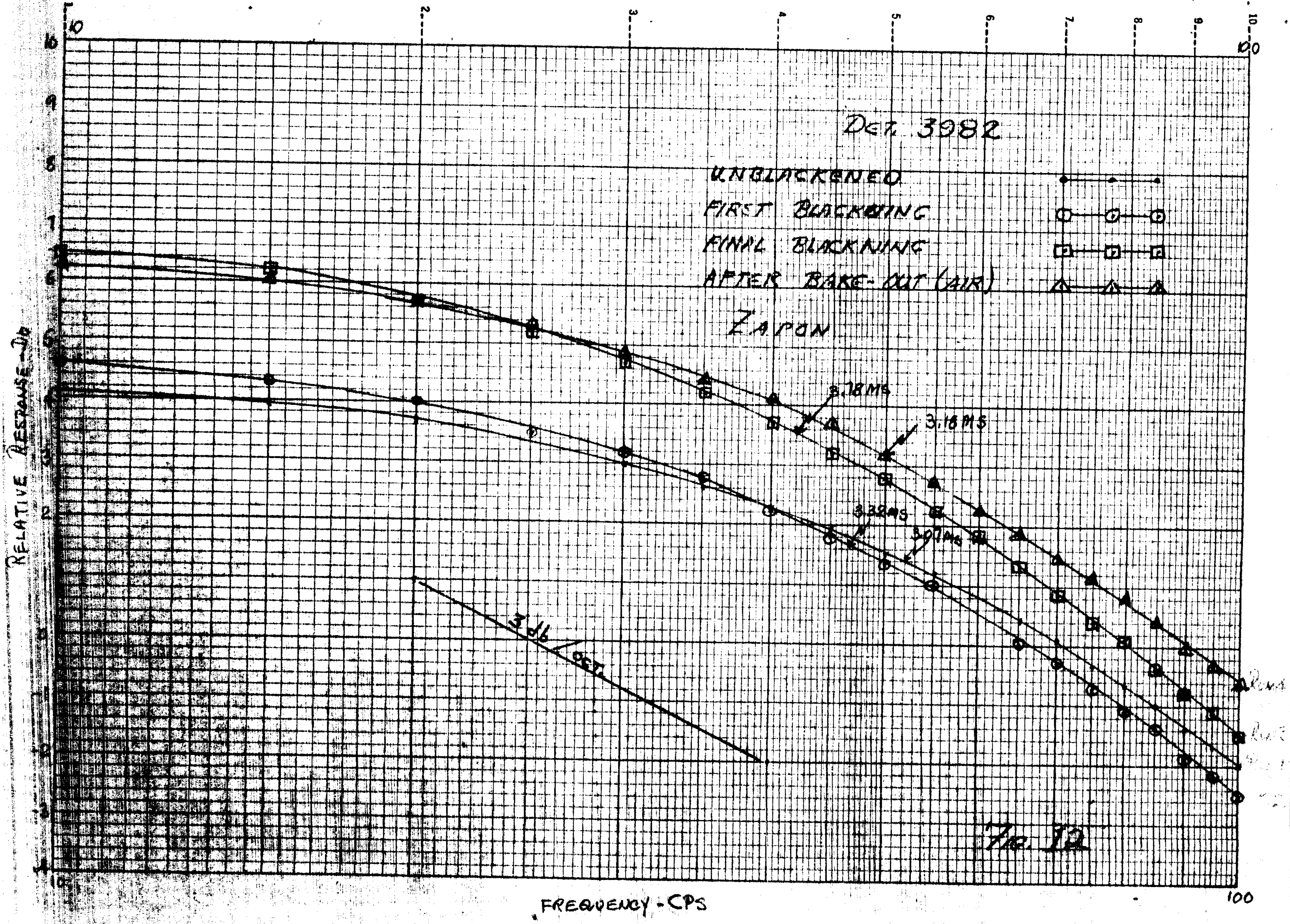
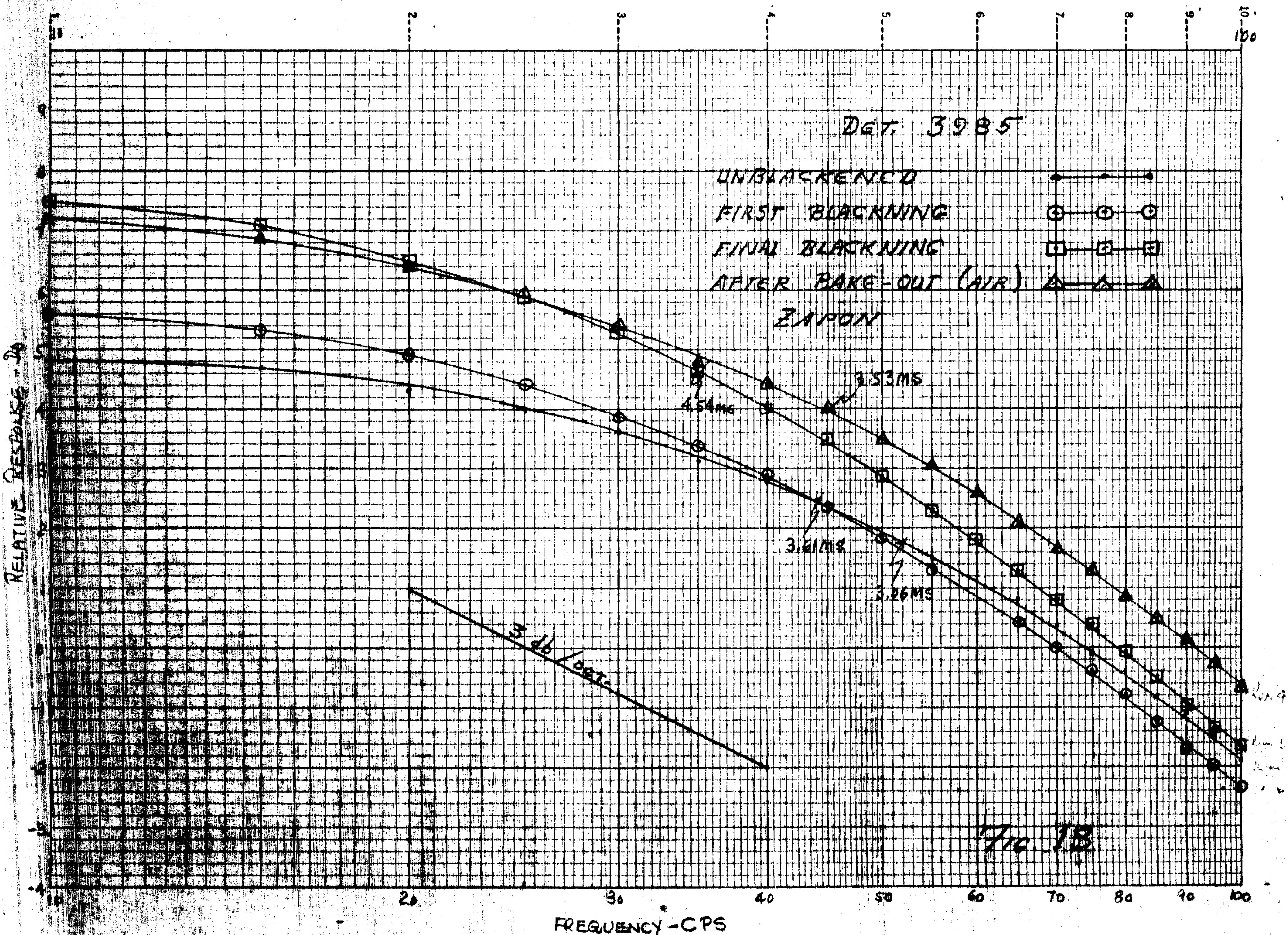
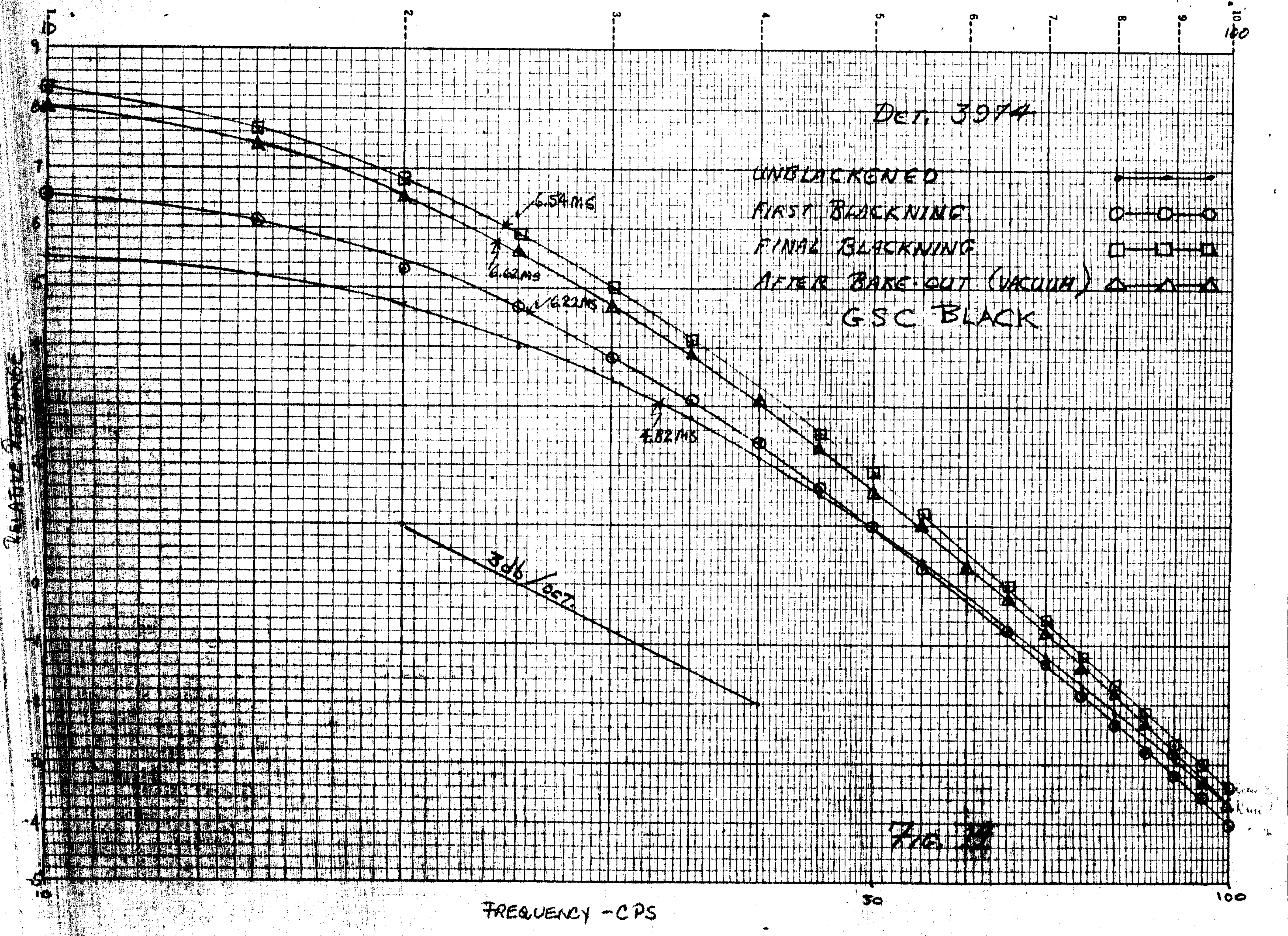

DET. 3982
UNBLACKENED
FIRST BLACKENING
FINAL BLACKNING
AFTER BAKE-OUT (AIR)
ZAPON
3.18 MS
3.18 MS
3.32 MS
3.07 MS
3 db OCT.
RELATIVE RESPONSE - Db
FREQUENCY - CPS
10
100

Fig. 12


DET. 3985
UNBLACKENED
FIRST BLACKNING
FINAL BLACKNING
AFTER BAKE-OUT (AIR)
ZAPON
3.53MS
4.54MS
3.61MS
3.66MS
3 db/oct.
RELATIVE RESPONSE - db
FREQUENCY - CPS
FIG. 1B

K+E SEMI-LOGARITHMIC 359-51G
KEUFFEL & ESSER CO. MADE IN U.S.A.
1 CYCLE X 70 DIVISIONS



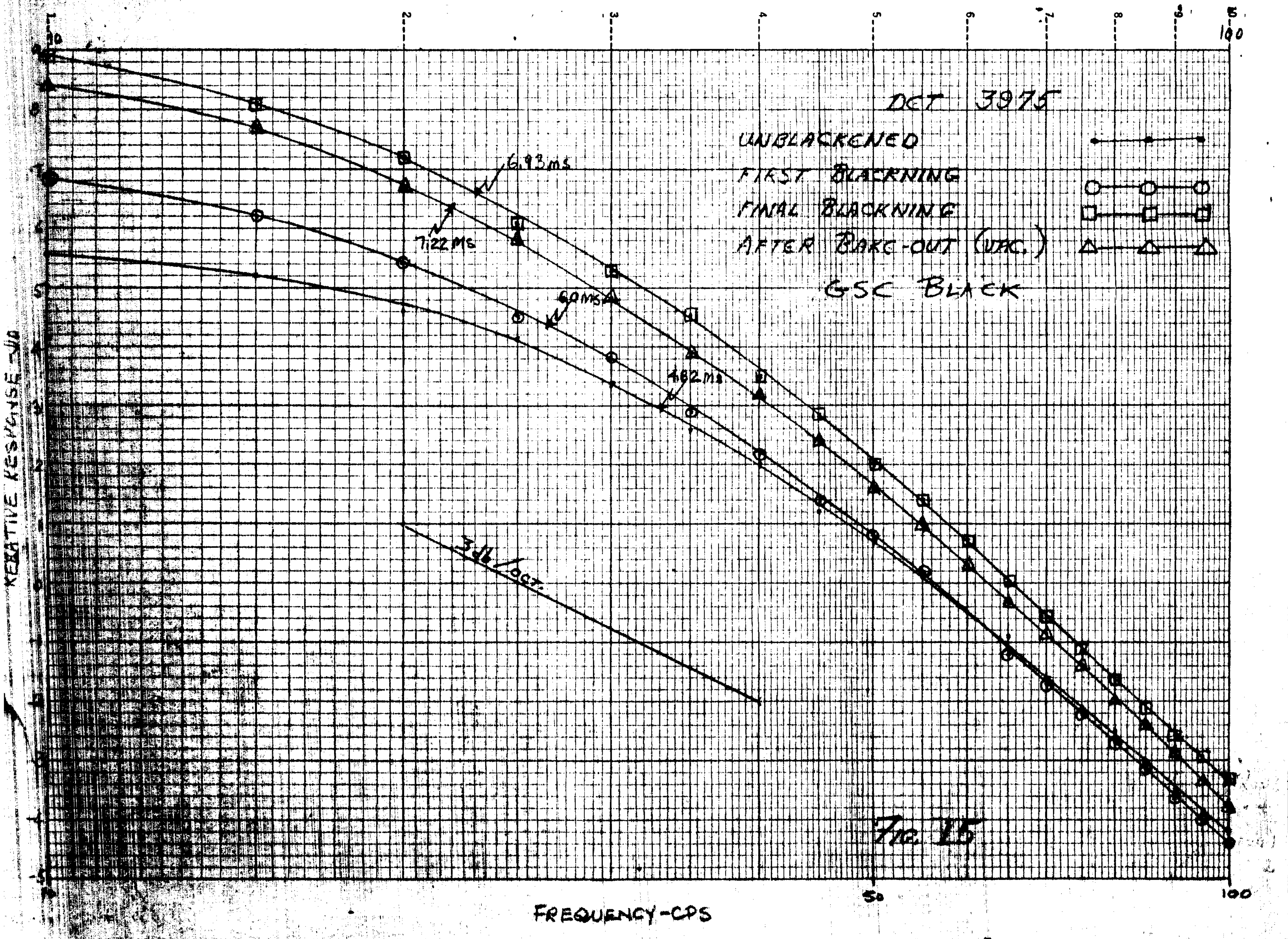
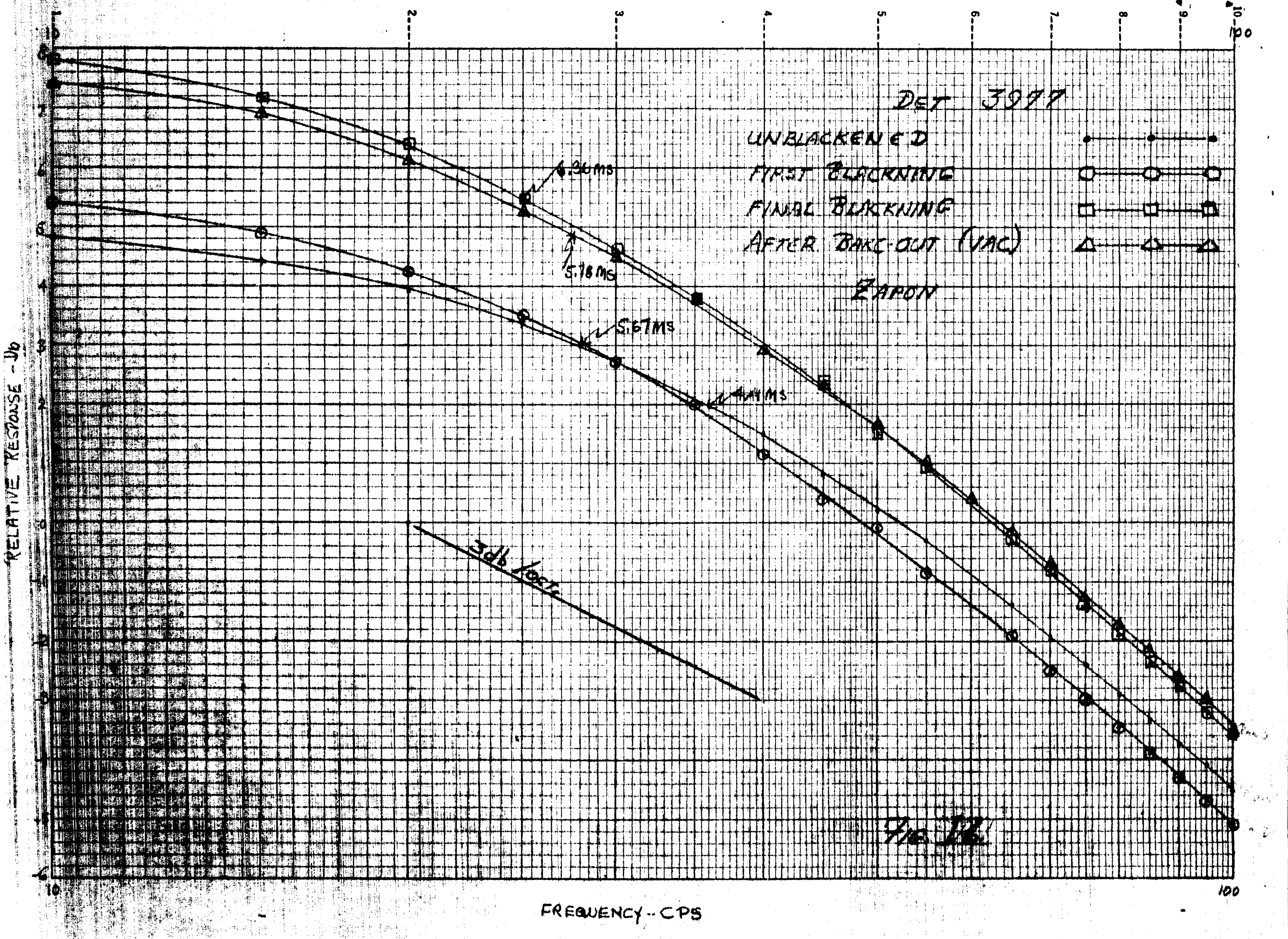
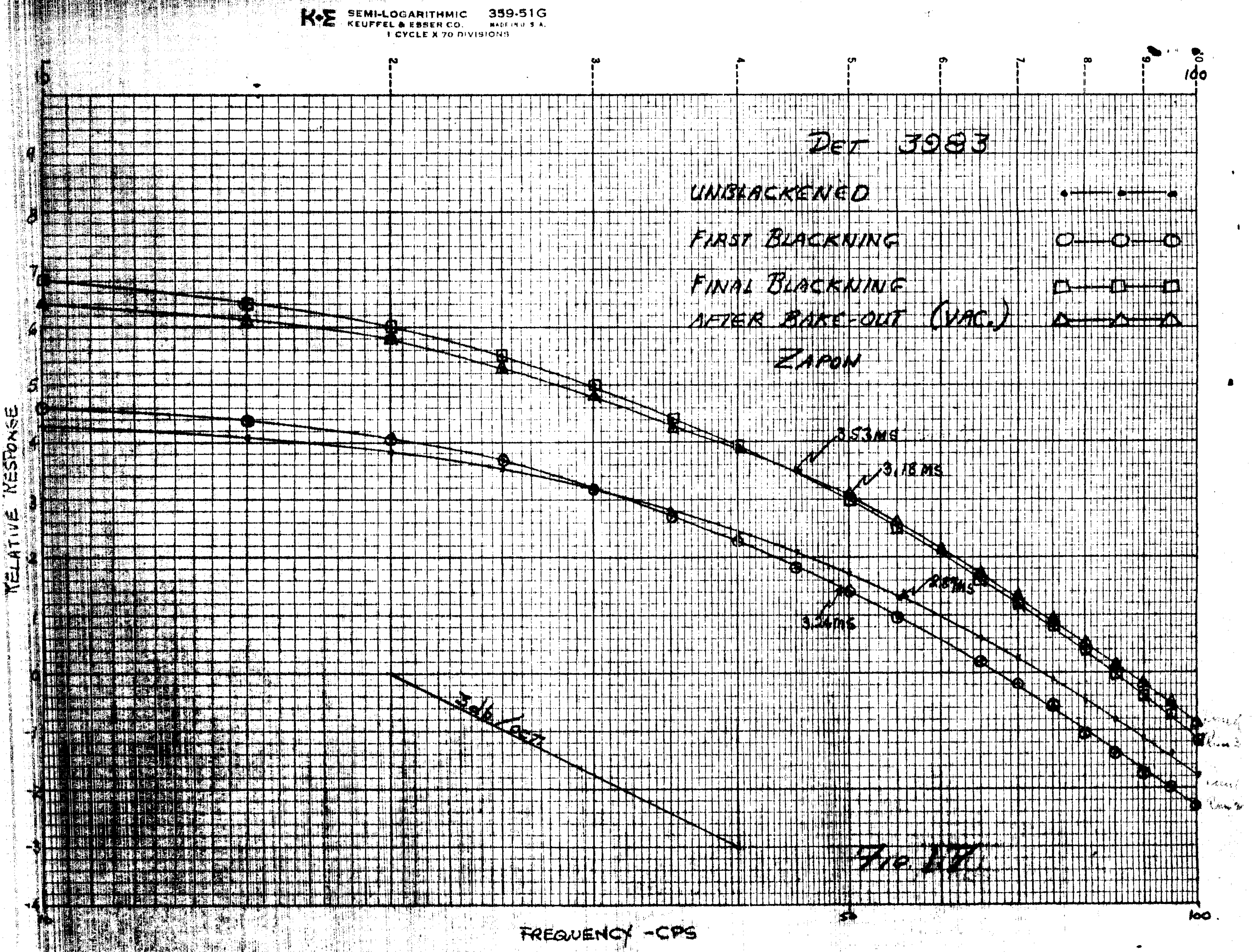

DCT 3975
UNBLACKENED
FIRST BLACKNING
FINAL BLACKNING
AFTER BAKE-OUT (VAC.)
GSC BLACK
6.93ms
7.22ms
6.0ms
4.82ms
3db/oct.
FREQUENCY-CPS
RELATIVE RESPONSE-db
50
100

FIG. 15

K•E SEMI-LOGARITHMIC 359-51G
KEUFFEL & ESSER CO. MADE IN U.S.A.
1 CYCLE X 70 DIVISIONS





K•E SEMI-LOGARITHMIC 359-51G
KEUFFEL & ESSER CO.
1 CYCLE X 70 DIVISIONS
DET 3983
UNBLACKENED
FIRST BLACKNING
FINAL BLACKNING
AFTER BAKE-OUT (VAC.)
ZAPON
3.53MS
3.18 MS
2.87MS
3.24MS
3db/oct
RELATIVE RESPONSE
FREQUENCY -CPS

Fig. IX